Analysis of Temperature Stresses in Fiber Reinforced Concrete Slabs by using EverFE Software

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Abstract: *Fiber reinforced concrete is one of the recent advancements in the field of concrete with improved properties like increased ductility, resistance to fatigue and impact etc. It can be used as surface course in rigid pavement construction. Temperature is one of the important factors which affects the design of rigid pavement and it is necessary to study the effect of temperature in fiber reinforced concrete slab. Prototype slabs of size 500 mm X 500 mm of thickness 150 mm and 200 mm of M-40 Grade concrete are cast and instrumented with K-type thermocouples for monitoring temperature at three different level viz., top, middle and bottom of the slab. Total four slabs, two conventional and two steel fiber reinforced concrete with a optimum dosage of 1.5% (Based on mechanical and Durability property) of thickness 150 mm and 200 mm are cast. The slabs are cured for 28 days and after that hourly temperature readings are taken over a period of 7 days. From the obtained data temperature stresses are calculated by using both Westergaards equations and Three-Dimensional Finite Element analysis (3DFE) using EverFE 2.24. It is found that temperature differential & temperature stress in Steel fiber reinforced concrete slab is less when compared to conventional concrete. Also, it can be concluded that the EverFE 2.24 software can be effectively used for the determination of temperature stresses.*

Keywords: Crack, Curing, EverFE 2.24, Fiber, Prototype, Temperature, Thermocouple.

1. INTRODUCTION

Cement concrete are gaining importance in recent times due to various advantages such as long life, minimum maintenance etc., These pavements are subjected to stress due to vehicular loads and the environmental factors. The repeated application of vehicular loads along with temperature variation may lead to development of cracks at the highly stressed locations. Though initial construction cost of concrete road is high, maintenance cost of concrete road is almost negligible. The major problem with concrete road is that due to fatigue action of wheel loads cracks are occurred which leads to the failure of the concrete roads. The fiber in concrete acts as crack arrester and helps to minimize the crack and enhance the quality of concrete roads.

Temperature variations within pavement structure leads to distress and possible failure of that structure. Daily and seasonal variations of temperature gradient across pavement depth must be considered in determining thermal stresses and calculating design parameters of rigid pavements.

1.1 Effects of Temperature in the concrete pavement

Temperature is an environmental factor that influences the performance of concrete pavements. Warping, which results from the temperature variation between the concrete pavement top and bottom surfaces, induces stresses in the pavement, as the pavement is restrained by its weight. The temperature stress induced by such interaction may result in early pavement cracking. This also results in a loss of subgrade or Base support along the slab edges or at the interior. The effect of the loss of subgrade support results in higher stresses as the sub-base becomes stiffer. This may become critical, particularly within a few hours after slab casted, since hydration of concrete at early stage may not have sufficient strength to prevent cracking. Temperature increase due to hydration does not immediately develop thermal stresses because of the process of stress relaxation or creep in the sconcrete. Thermal stresses arise when the temperature drops after its highest value and the concrete has finally set.

1.2 Temperature Stresses in Cement Concrete pavement

Temperature stresses can be categorised into two types – curling stresses and thermal- expansion stresses. Curling stresses result from temperature differential between the top and bottom of a Cement concrete pavement. The tendency to curl induces stress in the pavement as the pavement is restrained by its weight and support pressure from the below layers. Depending on the position of the vehicular load and the time of the day, curling stresses can be sufficiently high causing failure of the slab. Temperature stresses can also occur in CC pavements as a result of uniform temperature changes that cause the slab to contract or expand.

Whenever the top & bottom surface of a concrete pavement simultaneously possess different temperature, the slab tends to warp upward or downward inducing warping stress. Due to uniform temperature rise & fall in the cement concrete slab, there is an overall expansion & contraction of the slab. Since the slab is in contact with soil sub grade or the sub-base, the slab movements are restrained due to the friction between the bottom layer of the pavement & the soil layer. The frictional resistance between the Slab and the supporting layer tends to prevent the movement thereby inducing the frictional stress in the bottom fiber of the cement concrete pavement. Stress in slabs resulting due to this phenomenon vary with respect to the slab length.

Temperature tends to produce two types of stress in a concrete pavement these are,

1. Warping stress (curling stresses)

2. Frictional stresses

2. Finite element method

FE software's have been used to solve different pavement problems that could not be modelled using the simpler multi-layer elastic theory. Further, it provides a modelling alternative that is well suited for applications involving systems with irregular geometry, unusual boundary conditions, or non-homogenous composition. Various finite element software's have been developed for analysing the behaviour of cement concrete pavement. Most of the finite element models use an assemblage of two-dimensional plate bending elements to model behaviour of a concrete slab. The subgrade is usually assumed to behave like either a Winkler (dense liquid) or an elastic solid foundation. The Winkler foundation can be modelled by a series of vertical springs at the nodes, which means that the deflection at any point of the foundation surface depends only on the forces at that point and does not depend on the forces or deflections at any other points. The stiffness of the foundation is represented by the spring constant. The use of an elastic solid foundation assumes a homogeneous, elastic, and isotropic foundation with a semi-infinite depth. The deflection at any point depends on the forces at that point and also on the forces or deflections at other points.

2.1. EverFE software

EverFE (current version 2.24) is a 3D finite-element analysis tool for simulating the response of jointed plain concrete pavement systems to axle loads and environmental effects. EverFE has a highly interactive graphical user interface for model development and result visualization written in Tcl/Tk/Tix/vTk with finite-element code written in object-oriented C++. EverFE has been developed to analyse rigid pavements and an attempt to provide ease of access to 3D finite element analysis in a broad range of settings. It is stated that the program makes it simple and practical to explore effects of various factors such as temperature effects and dowelling on the behaviour of rigid pavements. This allows designers to perform parametric studies and evaluate different design and retrofit strategies. The EverFE design package incorporates graphical pre and post processing capabilities allowing for transparent generation of design models. Pavement configurations can be generated for complex pavement geometries with various factors controlled within minutes and solutions can be produced within a reasonable time from desktop computers.

2.2 Features of EverFE software

• Pavements can be modelled as 1, 2 or 3 slab/shoulder units longitudinally or transversely (maximum of 9 units).

• Tie bars and dowels can be specifically specified between units.

• A maximum of three elastic base layers may be specified with either a bonded or un-bonded base.

• Varied axle configurations/loadings can be defined and applied to the model.

• Linear, bilinear and tri-linear thermal gradients throughout the slab can be applied.

• Visualisations of stresses, displacements and internal dowel forces and moments. Critical values can easily be retrieved.

3. Objective of the present study

• To determine the temperature differential in Conventional and steel Fibre reinforced concrete slab.

• To evaluate induced stresses due to temperature in Conventional and steel Fibre reinforced concrete slabs using Westergaards equations.

• To evaluate induced stresses due to temperature in Conventional and steel Fibre reinforced concrete slabs using EverFE software.

4. LITERATURE REVIEW

Sunghwan Kim et al (2014), has developed Finite Element (FE)-based response models for investigating the early-age deformation characteristics of Jointed Plain Concrete Pavements (JPCP) under environmental effects. The FE-based ISLAB and EverFE software were used to conduct the analysis. The numerical models used in both the FE programs for computing slab deformation under environmental effects are briefly discussed in this paper. Sensitivity analyses of input parameters used in ISLAB 2000 and EverFE 2.24 had taken based on field and laboratory test data collected from instrumented pavements on highway US-34 near Burlington, Iowa. A good agreement of curling analysis results between ISLAB 2000 and EverFE 2.24 FE could be obtained when using dense liquid foundation model.

Kundan Meshram et al (2013), in the present study EverFE was used to calculate the effective K-value after providing layers above soil it is necessary to estimate effective k-value because of layers provided above soil increased its subgrade reaction. This improvement is due to compaction provided by layers. Percentage reduction in stress for 10 cm GSB and 15 mm DLC is 33.36% for single axle load and 43.90% for tandem axle load. The variation between the result of EverFE and Westergaards equation is negligible and does not exceed 14%. Thus, the design of rigid pavement effective k-value is needed for combination of layers and not separately. So, value must be known for combination of different layers.

Praveen Aggarwal et al (2016), in the present study plain cement concrete pavement has been analysed using 3-D mechanistic FEM computer programme EVERFE 2.24. Rigid pavement slab having dimension 4.5 x 3.5m which is generally taken in design. Subgrade is considered as tensionless dense liquid foundation and DLC as base course. Various material properties of component layer and loading pattern are varied to observe the effect of these factors on pavement stresses. Stresses in rigid pavement at critical location was calculated due to combined effect of axle load and environmental factor. These results are compared with IRC 58-2015 & 2002.

The flexural stresses given by IRC 58-2015 is upto 42% less than that given by IRC 58-2002, which is very large disparity and stresses given by EverFE 2.24 is nearly same as given by IRC 58-2002.

5. MATERIALS USED

5.1 Cement

In the present study 53 grade cement conforming to IS: 12269-1987 is used. The quantity of cement required for the experiment is collected from single source and stored in an airtight container. The results are as shown table 1.

Table –1: Properties of cement

Sl. No.	Test	Results	Requirements as per IS: 12269-1987
1	Fineness of cement	2.5%	Less than 10%
2	Standard Consistency	29%	Not Specified
3	Soundness	2.25 mm	Less than 10mm
Setting time (in minutes)			
4	Initial Setting time, min	132	Shall not be less than 30 minutes
5	Final Setting time, min	246	Shall not be more than 600 minutes

5.2 Fine aggregate

Locally available M-sand obtained from quarry near Bangalore is used. Sieve analysis was carried out for M-sand and the test results are shown in the table 2.

Table -2: Sieve analysis of fine aggregate

Sieve Size, mm	% passing	As per IS: 383 – 2016 (% passing)			
		Zone I	Zone II	Zone III	Zone IV
10.0	100	100	100	100	100
4.75	95.20	90-100	90-100	90-100	95-100
2.36	87.10	60-95	75-100	85-100	95-100
1.18	84.50	30-75	55-90	75-100	90-100
0.60	45.70	15-34	35-59	60-79	80-100
0.30	25.90	5-20	8-30	12-40	15-50
0.15	6.40	0-10	0-10	0-10	0-20

*The fine aggregate satisfies the requirement of grading Zone II as per IS 383-2016

5.3 Coarse aggregate

Coarse aggregate is those which are retained on 4.75 mm IS sieve. the common coarse aggregate are crushed stone from quarries. Locally available crushed granite coarse aggregate is used in this study. The tests for physical properties on coarse aggregate are conducted as per IS: 2386 and Confirming to IS: 383-2016 and tests results are shown in table 3.

Table -3: Test results of Coarse Aggregates

Sl No	Property	Test Results	Requirement as per IS: 383-2016
1	Aggregate Impact Value %	24.40	30% max
2	Abrasion Value %	24.60	30% max
3	Aggregate Crushing value %	25.50	30% max
4	Specific gravity	2.70	2.5-3.2
5	Water absorption %	0.32	2%
6.	Combined Flakiness and Elongation Index (%)	27.80	35% max

5.4 Fibres

Fibre is a small piece of reinforcing material possessing certain properties. They can be circular or flat. The fibre is often described by parameter called “aspect ratio”. The aspect ratio is the ratio of its length to its diameter. aspect ratio ranges from 30 to 150. In the present studies steel fibers are collected from Sanjay implex near Bilekahalli, Bengaluru. Properties of steel fibers are shown in table 4.

Table -4: Properties of crimped steel fiber

Property	Specifications
Density	7850 kg/m^3
Ultimate strength	1500 Mpa
Modulus of elasticity	2.0×10^5 Mpa
Poisson's ratio	0.28
Length	35 mm
Diameter	0.35 mm
Aspect ratio	80

*The properties are tabulated as provided by the manufacture.

5.5 Chemical admixture

Admixture is a material that is used as an ingredient in concrete that is added to the batch immediately before or during mixing. Superplasticizers (High Range Water Reducers) are relatively new category and improved version of plasticizer. They are chemically different from normal plasticizers. Use of superplasticizers permit the reduction of water without reducing workability. In the present investigation Sika is used as superplasticizer. The superplasticizer used in the present study is collected from "Durgamba Build Solutions" near RR Nagara in Bengaluru and the properties are in Table 5.

Table -5: Properties of superplasticizer (Sika fluid)

Property	Description
Form	Liquid
Colour	Light yellow
Relative density	1.080
pH value	4.3
Chloride content	<0.1
Alkali content	0.6
Dosage	0.6 %

*The properties are tabulated as provided by the manufacture.

6. MIX DESIGN

The minimum flexural strength required in cement concrete pavements to resist the load and temperature stresses under the worst exposure conditions as per specifications is 45 Kg/cm^2. Keeping this in mind proportioning of concrete mix to get the target cube strength of 40Mpa was initially aimed to satisfy the flexural requirements of the rigid pavements. Mix design is done as per IRC:44-2008. The mix proportions of different constituent materials are given in Table 6.

Table -6: Mix proportions of constituents

Material	Quantity
Cement	394 kg
M-sand	705 kg
Coarse aggregate	1274 kg
Water	149 lit.
Superplasticizer	2.349 lit.
W/C ratio	0.38
Mix proportion - **1:1.80:3.25**	

7. CASTING OF PROTOTYPE SLABS

Considering the importance of temperature stresses in cement concrete pavements in mind, an attempt has been made to study the temperature variations in the pavement slab of size 500 mm X 500 mm and with thickness of 150 mm and 200 mm made. In the present study steel fibers are used and the slabs are reinforced with optimum fiber content. Total of four slabs are cast i.e., two conventional, two SFRC slabs of thickness 150 mm and 200 mm. The results are compared with the conventional concrete specimens of the same dimensions. The moulds used for the present study are as shown in the figure 1.

Figure -1: Moulds of prototype slab

7.1 Subgrade preparation

A trench of was dug up to 50cms, and sieved soil is laid in the trench and well compacted up to 30cms and surface is levelled. Moulds are placed in the excavated trench. According to mix design cement, coarse aggregates, fine aggregates and water are mixed in proportion and laid and well compacted.

Figure -2: Subgrade preparation

Figure -3: Mixing of constituents

7.2 Slab Instrumentation

In the present study K-type thermocouples are used. The location for casting of the slab is identified such that it is exposed to sun light. The slab is directly cast on prepared earth surface. The thermocouple fixed to wooden beads of size 10 mm x 10 mm at three levels that is 25 mm from top, 25 mm from bottom and at the middle of the beads.

Figure -4: Fixing of thermocouples to wooden bead

7.3 Recording of temperature

Temperature are recorded after 28 days of casting and curing by using Digital thermometer indicator. The temperature indicator has two leads which are connected to the two leads of the thermocouple. the temperature indicator displays the temperature directly in degree centigrade. The temperature is recorded every hour for a period of 7 days.

Table -7: Temperature data collected for conventional concrete slab during summer season

Time	Air Temp.	Conventional (150mm)			Conventional (200mm)			Humidity (%)
		T	M	B	T	M	B	
1.00 AM	24	28	30	31	29	32	35	83
2.00 AM	23	28	30	32	29	30	31	85
3.00 AM	23	28	31	33	29	30	31	90
4.00 AM	23	28	31	33	29	30	31	85
5.00 AM	23	30	32	34	31	31	30	80
6.00 AM	23	30	32	34	31	31	31	75
7.00 AM	24	33	34	35	32	31	30	65
8.00 AM	26	34	34	33	33	31	29	50
9.00 AM	28	35	33	30	35	32	28	40
10.00 AM	28	35	33	31	35	32	28	55
11.00 AM	32	34	33	32	36	32	28	45
12.00 AM	34	37	35	32	37	34	30	40
1.00 PM	34	39	36	33	39	35	30	40
2.00 PM	34	42	38	33	43	37	31	40
3.00 PM	31	36	34	31	38	35	31	45
4.00 PM	29	35	34	32	36	34	31	51
5.00 PM	29	35	34	32	35	33	31	50
6.00 PM	28	34	33	32	34	33	32	55

7.00 PM	27	33	34	34	34	34	33	60
8.00 PM	26	33	33	33	34	34	33	65
9.00 PM	26	33	33	33	33	33	33	70
10.00 PM	26	32	32	32	33	33	32	68
11.00 PM	25	31	32	32	31	32	32	75
12.00 PM	24	30	31	32	31	32	32	80

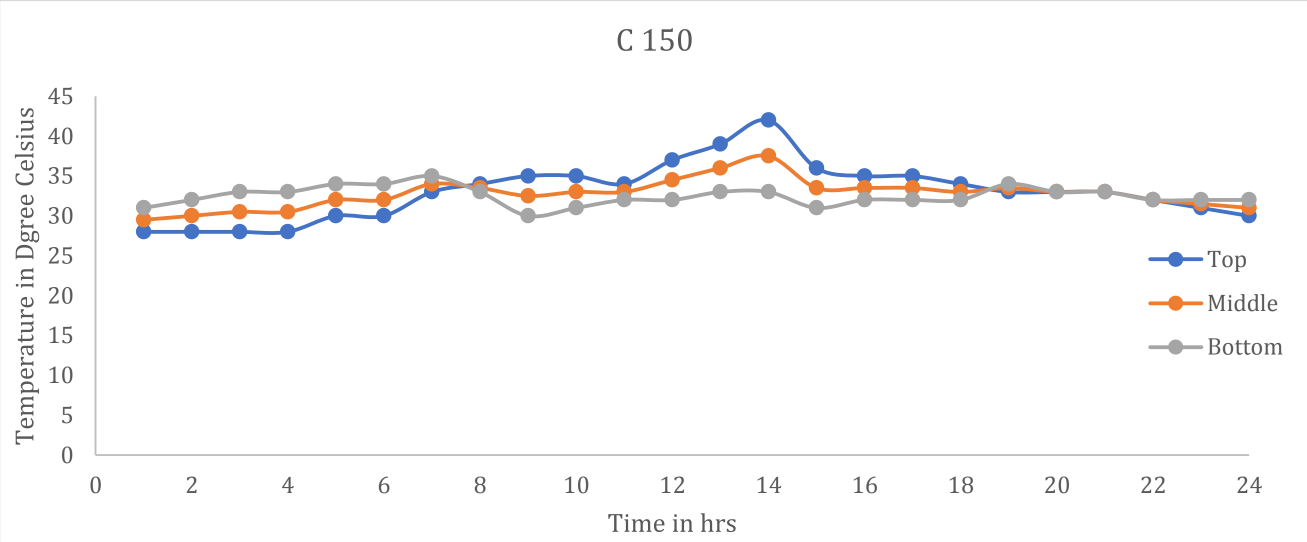

Chart -1: Variation of temperature with time for conventional concrete slab of thickness 150 mm

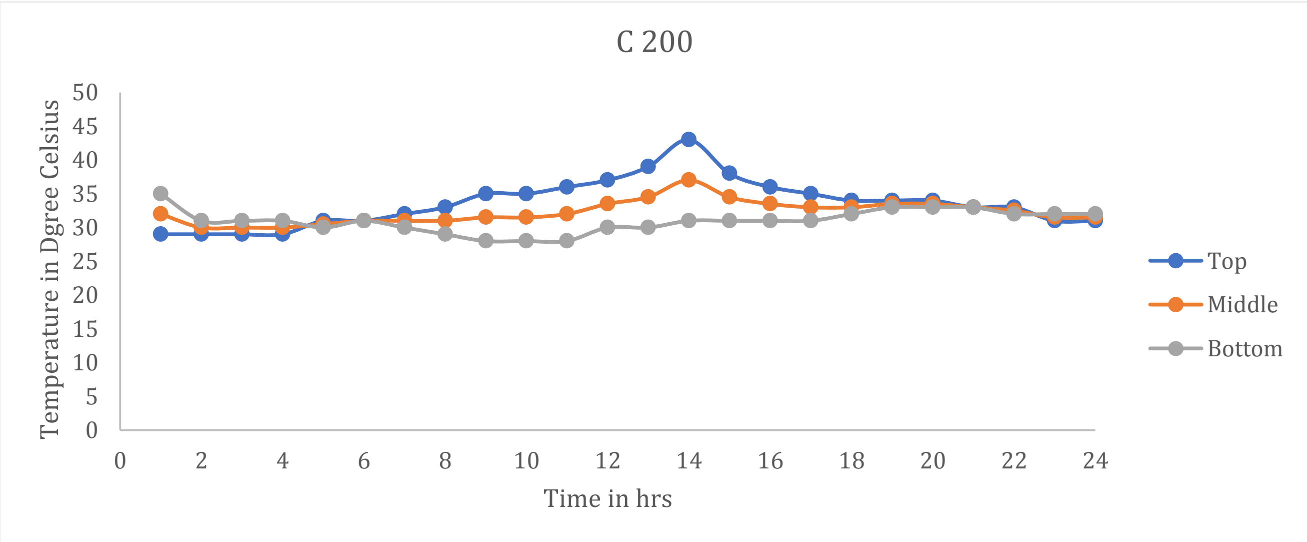

Chart -2: Variation of temperature with time for conventional concrete slab of thickness 200 mm

Table -8: Temperature data collected for steel fiber reinforced concrete slab during summer season

Time	Air Temp.	SFRC (150mm)			SFRC (200mm)			Humidity (%)
		T	M	B	T	M	B	
1.00 AM	24	29	30	31	29	31	32	24
2.00 AM	23	29	31	32	29	30	31	23
3.00 AM	23	29	30	31	28	30	31	23
4.00 AM	23	29	30	30	29	30	31	23

5.00 AM	23	28	29	30	28	30	31	23
6.00 AM	23	28	29	29	28	29	30	23
7.00 AM	24	30	30	30	32	32	32	24
8.00 AM	26	31	31	31	33	33	32	26
9.00 AM	28	31	31	30	33	32	30	28
10.00 AM	28	33	32	30	34	33	31	28
11.00 AM	32	35	33	31	36	33	30	32
12.00 AM	34	38	35	32	40	36	32	34
1.00 PM	34	41	39	36	41	39	36	34
2.00 PM	34	40	38	36	39	38	36	34
3.00 PM	31	35	34	32	36	35	34	31
4.00 PM	29	33	33	32	34	34	33	29
5.00 PM	29	33	32	31	33	33	32	29
6.00 PM	28	32	32	31	32	32	32	28
7.00 PM	27	32	33	33	32	33	33	27
8.00 PM	26	31	32	32	32	33	33	26
9.00 PM	26	32	32	32	31	32	33	26
10.00 PM	26	31	31	31	31	32	33	26
11.00 PM	25	30	31	31	29	29	29	25
12.00 PM	24	29	30	30	29	31	32	24

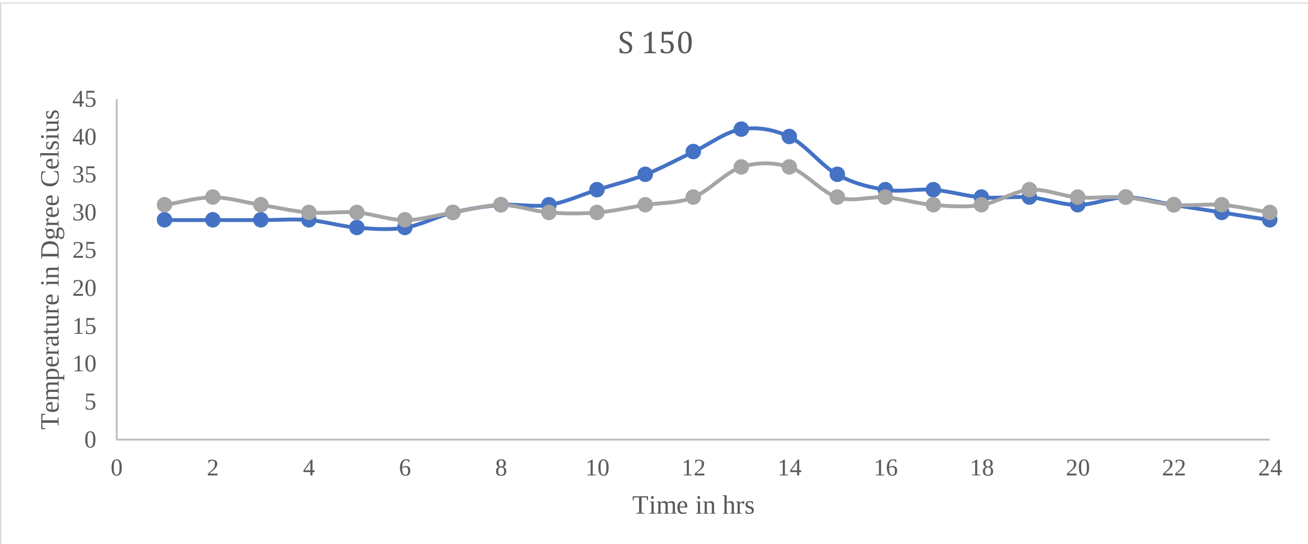

Figure -3: Variation of temperature with time for steel fiber reinforced concrete slab of thickness 150 mm

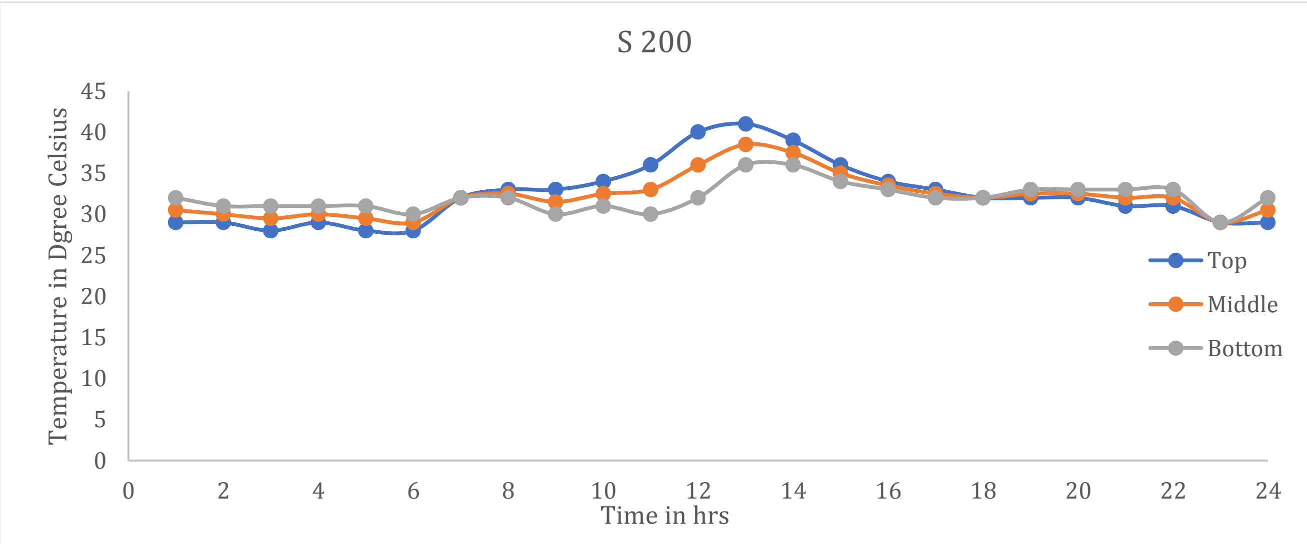

Chart -4: Variation of temperature with time for steel fiber reinforced concrete slab of thickness 200 mm

8. CALCULATION OF TEMPERATURE STRESSES

Due to variation in the temperature and contraction of the concrete slab thermal stress are developed in pavement. temperature stress is a very important factor to design the pavement. To determine the temperature stresses in concrete slabs the temperature differentials measured are considered. The temperature stresses are evaluated using Westergaards equations in a pavement slab of standard size 4500 mm X 3500 mm.

Table -9: Maximum temperature stresses developed in the slabs using Westergaards equation

Type of slab	Temperature stress, kg/cm²		
	Thickness, mm	150	200
		Interior	Interior
Conventional M-40	Due to positive T.diff.	18.79	20.54
SFRC		16.16	17.18
Conventional M-40	Due to negative T.diff.	10.27	10.44
SFRC		7.94	8.54

8.1: Calculation of temperature stress by using EverFE software

Step-I: Geometry menu

The geometry panel allows specification of the basic geometry of the rigid pavement system. Any changes to the system geometry are immediately reflected in the plan and elevation views shown in the left half of the EverFE input panel. The plan and elevation views can be scaled by clicking the ZM Out and ZM In buttons at the top centre of the input panel, or manually entering a scale factor. The default scale factor is 1.00.

Column length (X mm) - 4500

Row width (Y mm) - 3500

Thickness (Z mm) - 200

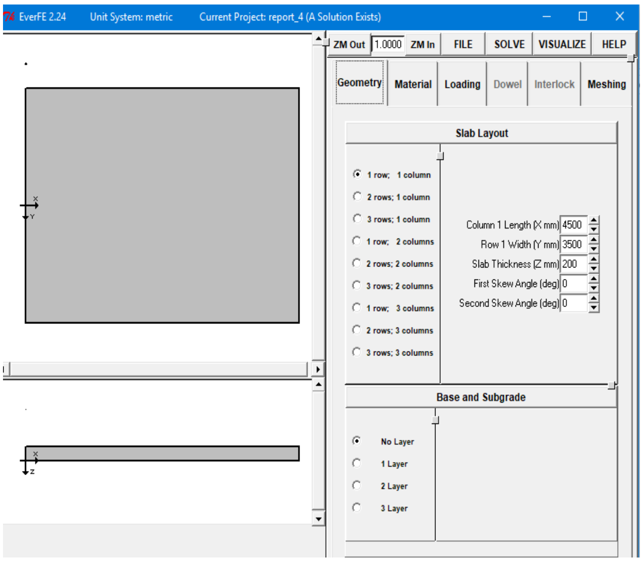

Figure -5: Snapshot of geometry menu

Step-II: Material menu

The slabs are treated as linearly elastic solids, and thus the user must specify the modulus of elasticity E, Poisson's ratio μ, the coefficient of thermal expansion α, and the slab density. Except for slabs founded directly on a tension-supporting dense liquid, the slab density must be included in an analysis to accurately predict stresses. Including slab density is especially important when considering curling of a slab founded on an elastic solid base, where the primary loading on the slab is due to its own self-weight. Thus, the default slab density corresponds to that for normal-weight concrete.

E-value (Young's modulus), Mpa - 38115

Poisson's ratio (μ) – 0.15

Coefficient of thermal expansion(α), /^{0}C – 10 x 10^{-6}

Density (ρ), kg/m^3 - 2400

Modulus of subgrade reaction (K), kg/m^3 – 5.5

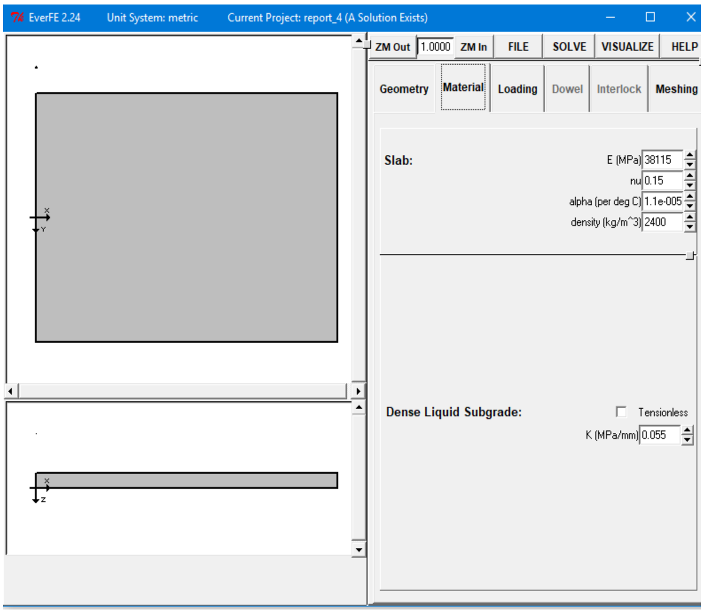

Figure -6: Snapshot of material menu

Step-III: Loading menu

Linear, bilinear, and trilinear thermal distributions can be specified in EverFE. This is accomplished by giving the number of temperature changes (2, 3 or 4), and specifying their value. The temperature changes are assumed to be, equally spaced through the slab thickness from top to bottom.

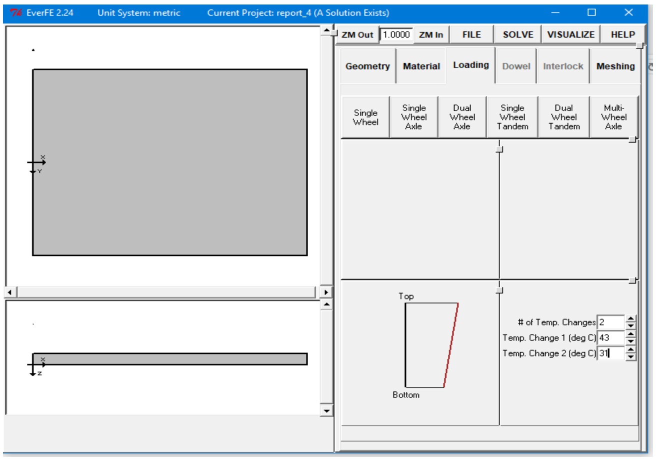

Figure -7: Snapshot of loading menu

Step-IV: Meshing menu

The finite-element meshes generated by EverFE are rectilinear. The number of elements in the x-direction for each column of slabs, and in the y-direction for each row of slabs, are specified independently. In addition, the number of elements through the thickness of the slab and each elastic base/subgrade layer are also user-specified. However, the number of elements through the slab thickness may be limited by the simulation of a bilinear or trilinear thermal gradient.

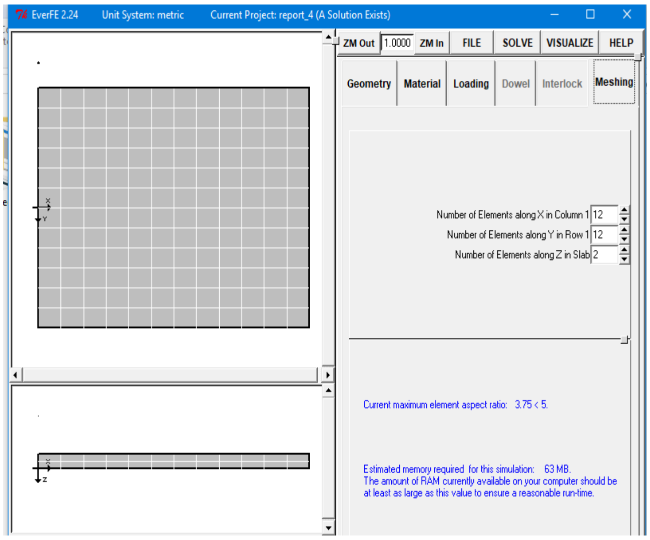

Figure -8: Snapshot of meshing menu

Step-V: Solver menu

This option allows the FE solver to be executed for the displayed model in its current configuration.

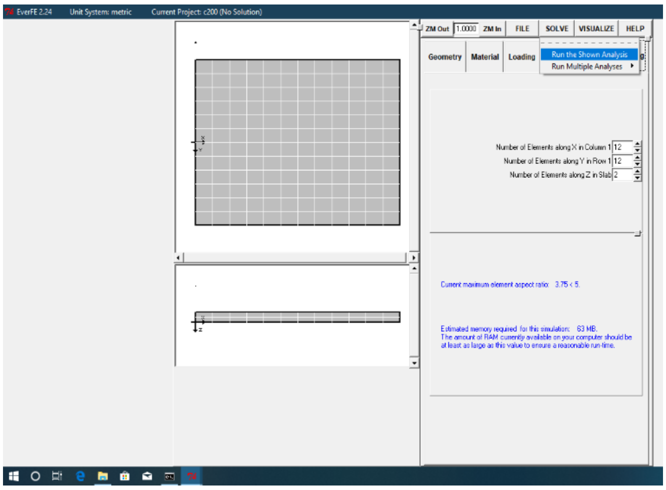

Figure -9: Snapshot of solver menu

Step-VI: Visualization menu

In the visualization menu stresses, results for points and displacement can be viewed.

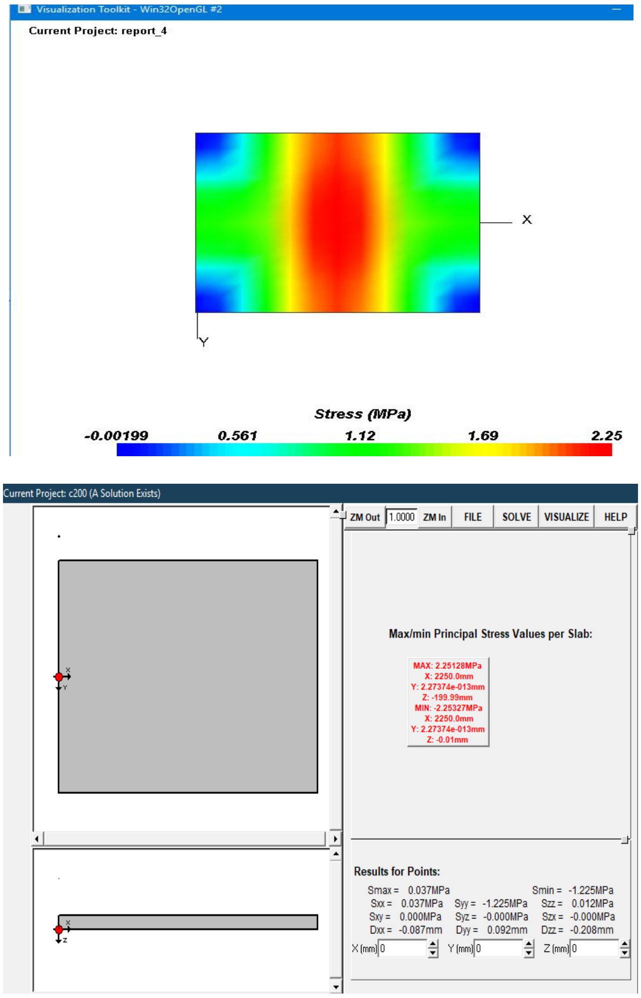

Figure -10: Snapshot of results menu

Table -10: Comparison of maximum temperature stresses in the slabs

Type of slab	H in mm	Temperature stress, kg/cm²			
		150		200	
		Interior	Ever FE	Interior	Ever FE
Plain M-40	Due to +ve T.diff	18.79	20.57	20.54	22.50
SFRC		16.16	17.69	17.18	18.81
Plain M-40	Due to -ve T.diff	10.27	11.24	10.44	11.43
SFRC		7.94	8.69	8.54	9.35

*H-Thickness

9. CONCLUSONS

- The obtained temperature differentials are lower than values suggested by IRC 58-2015 for the design of concrete pavement.

- Temperature differential is more in conventional concrete slab when compared to steel fiber reinforced concrete slabs.

- Temperature stresses calculated from EverFE software are almost 9.80% greater than that calculated from Westergaards equations.

- 3D finite element software (EverFE) can be effectively used for quantifying the temperature stresses.

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BIOGRAPHIES

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